

EXTENSION NOTE

March 2000 EN-048

- At two study sites in the Nelson Forest Region, soil physical properties were significantly affected by compaction, including light compaction, that was caused by machines used to conduct pushover tree harvesting.
- Soil compaction is expected to negatively affect growth of regenerated trees. Tree growth response on the study sites is being monitored.
- Several recommendations are made for minimizing soil compaction on pushover harvesting sites, including: use designated skid trails, rehabilitate trails, and conduct pushover harvesting on frozen soils.



forest sciences

NELSON FOREST REGION

Shelterwood Harvesting in Root Disease Infected Forests in Southeastern British Columbia: Post-Harvest Soil Compaction—EP 1186

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INTRODUCTION

In 1993, the Forest Sciences Section, Nelson Forest Region (NFR) designed and initiated a project to test the use of partial cutting in root disease infected areas, and to test the effectiveness and operational feasibility of root disease treatments in both clearcut and shelterwood silvicultural systems. The trial is being conducted at two sites: one site is located near Golden, British Columbia (BC) and is infected with *Tomentosus* root disease; the other site is near Nakusp, BC and is heavily infected with *Armillaria* root disease.

Site characteristics, soil disturbance hazards, harvesting practices, and other studies on the two sites are described in Delong (1995) and Nelson Forest Region (1996). Soil disturbance was previously summarized in Quesnel and Curran (1999a). Project design, statistical details, and data analysis are presented in Quesnel and Curran (1999b).

Pushover harvesting frequently causes more detrimental site disturbance than conventional ground skidding plus mechanical site preparation (Davis and Wells 1994). Soil scientists are also concerned that partial cutting systems may have undesirable effects on soils by reducing the productive landbase due to greater permanent access requirements, potentially greater length of active roads, and repeated use of skid trails during the rotation. Potentially detrimental disturbance is often associated with soil compaction, which causes alterations in soil physical properties that can adversely affect tree growth (Greacen and Sands 1980). Assessing the effects of these harvesting methods on soil compaction may provide support or direction for modifying site-disturbance guide-

lines in the Forest Practices Code of British Columbia (FPC).

SITE DESCRIPTIONS

The Golden site is located on the Mount 7 Forest Service road, 4 km east of town, in the Interior Cedar-Hemlock moist cool (ICHmk1) / Montane Spruce dry cool (MSdk) subzone transition. Surface soils are predominantly silt loam and loam textured (12-24% clay, 41-64% silt) with 10-20% coarse fragments. Calcareous parent material with high pH (7.3-8.2) occurs at 30 to 70 cm depth, and the soils are classified as Orthic Eutric Brunisol (Utzig 1991). The Golden site is west to north facing, with slopes ranging from 5 to 35%.

The Nakusp site is located on Ice Road, about 50 km south of Nakusp, in the Interior Cedar-Hemlock moist warm (ICHmw2) subzone. Surface soils are predominantly loam and fine sandy loam textured with 10-35% coarse fragments, parent materials are noncalcareous, and the soils are classified as Orthic Humo-Ferric Podzol (Jungen 1980). The Nakusp site is north facing with slopes ranging from 25 to 35%.

STUDY DESIGN

At each site, eight treatments were established, with two replicates per treatment, for a total of 16 one-hectare (100x100-m) treatment units. The Undisturbed controls are not of interest for current disturbance measurements or compaction sampling. Only the clearcut and heavy shelterwood, for both hand-felled and pushover treatments, were sampled for compaction; this yielded compaction samples from eight treatment units on each site, consisting of two replicates for each of four treatments.

Treatments:

1. Hand-felled clearcut *¹
2. Hand-felled light shelterwood
3. Hand-felled heavy shelterwood *
4. Control (for conventional)
5. Pushover clearcut *
6. Pushover light shelterwood
7. Pushover heavy shelterwood *
8. Control (for pushover)

HARVESTING

The Golden site was harvested January to March 1995. Snow depth ranged from 20 to 35 cm during harvesting. Soils were not frozen except on the main skid trails. Rubber-tired skidders were used in the clearcut blocks and on the main trails. The shelterwood blocks were yarded with a crawler-tractor. An excavator was used for pushover felling. Main skid roads were located outside the blocks and were designated before harvesting.

Random skidding was used inside the blocks. Main skid trail rehabilitation, fluffing, and cross-ditching was carried out by the excavator.² For the first two pushover blocks, whole trees were skidded out of the block, roots were bucked off, and the stumps were then skidded back to the block. The operator also attempted to refill the stump holes, using woody debris and limbs as well as mineral soil. This extra machine movement and activity on these two blocks was likely responsible for additional scalping and compaction, and for accumulations of woody debris, thus yielding poor planting spots. Therefore, stumps were bucked on the site for the rest of the trial, and stump holes were not intentionally refilled.

The Nakusp site was harvested January to March 1996. Snow depths averaged 50 cm compressible snow (Lewis and Timber Harvesting Committee 1991, p.35) during harvesting. Soils were not frozen except on the main skid trails. The harvesting methods were modified at the Nakusp site to reflect experience gained at the Golden site. Also, supervision of harvesting on the pushover blocks at the Nakusp site was more intensive to minimize influences due to limited operator experience. Rubber-tired skidder activity was restricted to designated trails outside of treatment units. The within-block trails were used only by small crawler-tractors or by the excavator used for pushover harvesting. Where possible, snow trails were constructed to minimize soil disturbance. Skid trails were cross-ditched, but not rehabilitated, at the Nakusp site.

FIELD AND LABORATORY METHODS

Soil disturbance measurements followed the procedures outlined in the Soil Conservation Surveys Guidebook (BCMOF and BCMOE 1997). Additional observations were made and these are described in detail in Quesnel and Curran (1999b).

At each 1-m intercept point along the measurement transects, counted soil disturbance and forest floor displacement information were recorded. After all disturbance measurements were completed, ten sample points that had previously been marked for Repeated Machine Traffic, and a paired Undisturbed site, were randomly

selected for compaction sampling in each treatment unit.³ A sample point that showed evidence of compaction on 100% of a 1x2-m rectangle was considered to have incurred repeated machine traffic. Compaction evidence includes:

- altered soil structure,
- increased density relative to surrounding soil,
- puddling, or
- compacted deposits of organic material that cannot be readily excavated by a shovel.

For a single treatment unit of the conventional and pushover clearcut treatments on each site, an additional ten random points were selected for sampling Light-Moderate compaction.⁴ This soil disturbance category includes compacted areas with density increases, as observed by a surveyor, estimated to be below the threshold specified by the FPC.

At each sample point, a core soil sample (2x5 cm) was collected from two depths (2-4 cm and 6-8 cm). Laboratory analysis included the following physical properties: total bulk density, total porosity, aeration porosities at 5 J/kg and 10 J/kg, and available water-storage capacity.

DATA ANALYSIS

With the exception of aeration porosity and total porosity at the Golden site, all physical properties (e.g. measures of soil compaction) on both sites had a nonsignificant response to harvesting method, basal area retention, and the interaction between these factors. Thus, a simpler analysis of variance (ANOVA) design was used to test for the effect of compaction on soil physical properties. The ANOVA compared the factors of soil disturbance category (Repeated Machine Traffic, Undisturbed) and depth (2-4 cm, 6-8 cm), on both sites as a combined data set, and then on each site independently. A subset of the data was analyzed to compare the Repeated Machine Traffic, Undisturbed, and Light-Moderate compaction categories on the two plots sampled for Light-Moderate compaction. Summary statistics and graphs were also generated for all physical properties on both sites.

RESULTS AND DISCUSSION

Effects of Repeated Machine Traffic on Soil Physical Properties

Overall, the soils at the Golden site had significantly greater average values for total bulk density ($P=0.001$) than the soils at Nakusp (Figure 1). Thus, for each combination of depth and disturbance category, the corresponding values were lower at the Nakusp site. The Nakusp soils had higher sand content, based on hand texturing, and appeared to have more incorporated organic matter; both of these properties yield lower density soils. The total bulk density was also significantly greater

¹ * = treatment sampled for compaction.

² K. Gosal, Consulting Forester, Golden; personal communication, March 1996.

³ "Repeated Machine Traffic" (E) and "Undisturbed" (U) are soil disturbance categories, as specified in the FPC soil conservation guidebook (BCMOF and BCMOE 1997).

⁴ The "Light-Moderate" soil disturbance category was established by the authors for the purpose of this study.



at 6-8 cm than at 2-4 cm depths across both sites and at each site individually ($P=0.0218, 0.0032, 0.0037$) (Figure 1). Increased bulk density with depth is the usual condition in soils (e.g., Smith and Wass 1994; Wass and Smith 1997). For total bulk density, compacted (Repeated Machine Traffic) samples were significantly denser than Undisturbed samples at Golden ($P=0.0065$) (Figure 1).

Depth was a significant factor across both sites ($P=0.0441$) and at each site ($P=0.0046, 0.0063$) for total porosity. Total porosity was significantly greater for the 2-4 cm depth than the 6-8 cm depth (Figure 2). Total porosity was significantly less for compacted (Repeated Machine Traffic) than Undisturbed samples at both sites ($P=0.0043, 0.0439$) (Figure 2). However, the relative magnitude of the decrease in total porosity was less than the decrease in aeration porosity at 10 J/kg caused by compaction (Figures 2 and 3). The change in aeration porosity is considered more critical, as explained below.

The response patterns for both aeration porosities were similar, and only aeration porosity at 10 J/kg will be discussed here. The aeration porosity at 10 J/kg at 2-4 cm depth was significantly greater than the 6-8 cm depth ($P=0.0074$) at Golden, but depth was not a significant

factor at Nakusp (Figure 3). Significantly less aeration porosity at 10 J/kg was found for compacted (Repeated Machine Traffic) samples at both sites ($P=0.0004, 0.0027$). Loss of aeration porosity as forest soils are compacted is considered one of the main reasons why tree growth is reduced, especially on finer textured soils (Greacen and Sands 1980; Froehlich and McNabb 1984). In the Rocky Mountain Trench near Cranbrook, a post-harvesting study on finer textured soils used Undisturbed soil to compare the relative change in compacted soil for aeration porosity at 10 J/kg and total bulk density (Utzig and Thompson 1992). These authors found that the relative reduction in aeration porosity could be greater than the relative change in total bulk density for compacted soil.

The available water-storage capacity at the 2-4 cm depth at Nakusp was greater than the 6-8 cm depth ($P=0.0002$) while there was no significant difference with depth at Golden (Figure 4). The surface soil horizon at Golden is more uniform for this physical property than the soil at Nakusp. The available water-storage capacity for compacted soil (Repeated Machine Traffic) was significantly greater than the Undisturbed soil at both sites ($P=0.0141, 0.0053$) (Figure 4). In general, available water-storage capacity, for surface horizons in this study, were increased

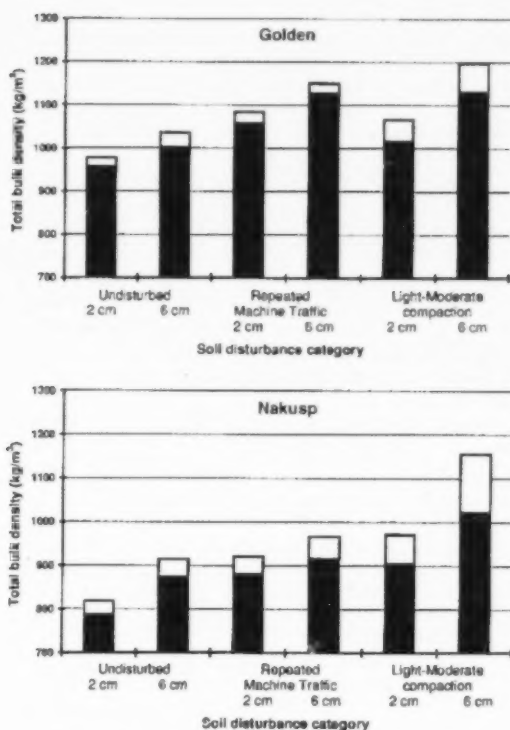


Figure 1. Total bulk density at the Golden and Nakusp study sites, for three soil-disturbance categories. The solid bar is the mean. The open bar indicates the standard error, with $n=8$ for Undisturbed and Repeated Machine Traffic, and $n=2$ for Light-Moderate compaction.

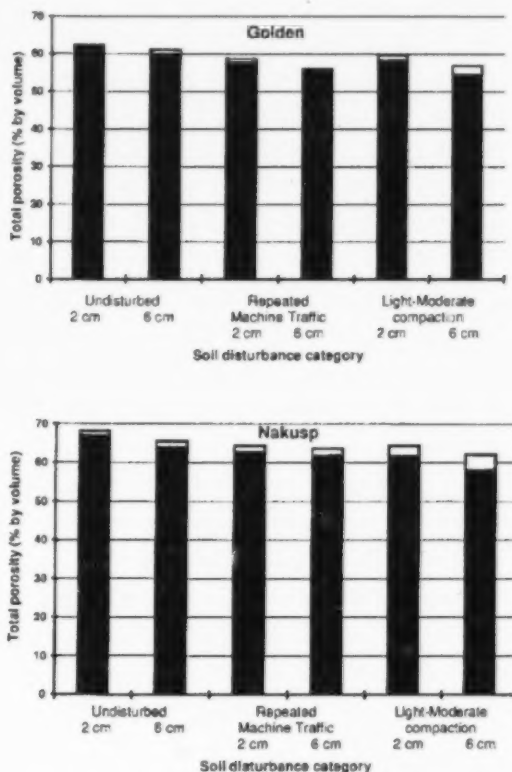


Figure 2. Total porosity at the Golden and Nakusp sites, for three soil-disturbance categories. The solid bar is the mean. The open bar indicates the standard error, with $n=8$ for Undisturbed and Repeated Machine Traffic, and $n=2$ for Light-Moderate compaction.



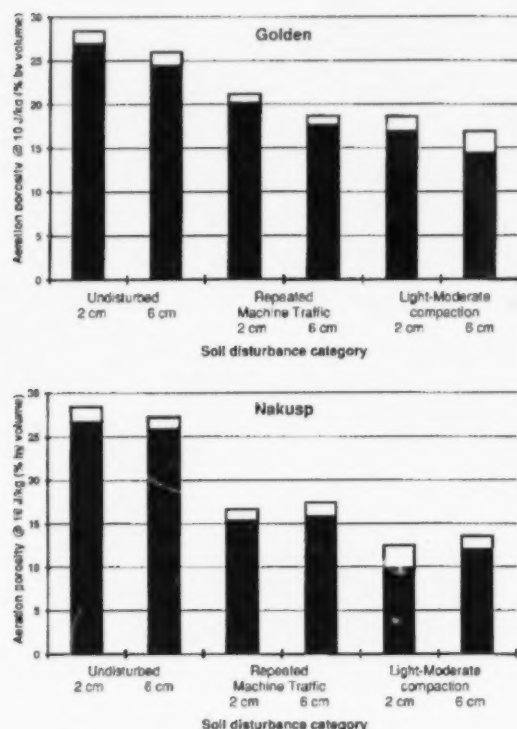


Figure 3. Aeration porosity at 10 J/kg at the Golden and Nakusp study sites, for three soil-disturbance categories. The solid bar is the mean. The open bar indicates the standard error, with $n=8$ for Undisturbed and Repeated Machine Traffic, and $n=2$ for Light-Moderate compaction.

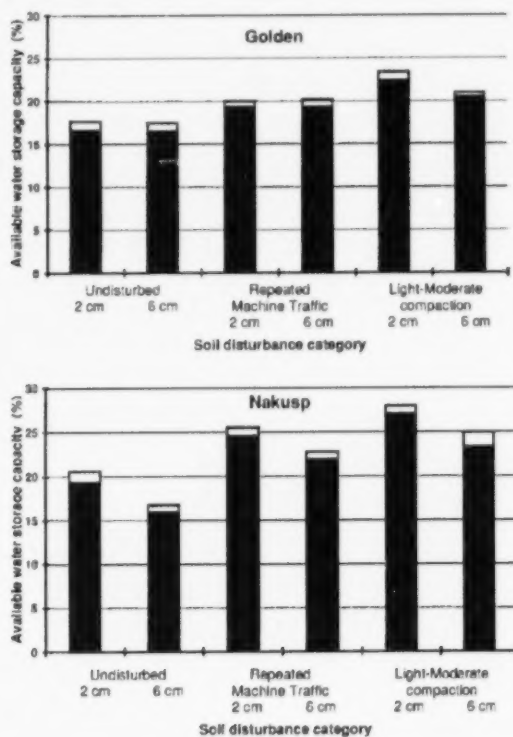


Figure 4. Available water storage capacity (% by soil volume) at the Golden and Nakusp study sites, for three soil-disturbance categories. The solid bar is the mean. The open bar indicates the standard error, with $n=8$ for Undisturbed and Repeated Machine Traffic, and $n=2$ for Light-Moderate compaction.

by the compaction caused during excavator destumping. Increased water retention occurs in compacted soils if aeration macropores are reduced in size to micropores (Greacen and Sands 1980). However, the reader is cautioned that this benefit of greater water storage on these sites may be offset by decreased aeration porosity and increased total bulk density. This may cause an offsetting decrease in tree growth. The reduced aeration or macroporosity usually yields reduced soil infiltration rates, which may result in greater runoff and increased surface erosion.

Light-Moderate Compaction

Undisturbed soil was significantly different from the other two disturbance categories for all physical properties, except total bulk density, at Nakusp ($P=0.0004-0.0323$) and for aeration porosity at 10 J/kg at Golden ($P=0.0359$). The disturbance categories of Repeated Machine Traffic and Light-Moderate compaction were not significantly different from each other for any physical property measured at either site. The frequency of Light-Moderate compaction was 0-3.6% (mean = 1.2%) at Nakusp and 0.2-16.3% (mean = 6.5%) at Golden. The treatment unit with the highest frequency for the disturbance category Light-Moderate compaction was a hand-felled clearcut

at Golden (16.3%). Thus, up to 16% of a treatment unit could have compaction that is not countable under the FPC, due to less area being compacted or a less-apparent change in density observed in the field. These microsites would have altered physical properties essentially the same as countable soil compaction. It indicates that the effects on soil physical properties, in some instances, may not be fully represented by FPC countable disturbance. Studying random skidding, Utzig and Thompson (1992) also found compacted sample points with significant decreases in aeration porosity at 10 J/kg but with an area less than the minimum size for countable disturbance.⁵

Effects of Compaction on Soil Properties and Tree Growth

Compaction of surface soils by harvesting machines can inhibit or reduce growth of tree regeneration by impeding

⁵ During May 1999, Curran observed that light-moderate compaction disturbances on one of the sites of Utzig and Thompson still had structural characteristics that were different from the adjacent undisturbed sample points. This included a coarse, platy structure, caused by machine traffic, that has persisted for eight years since harvesting.

root penetration, reducing gas exchange for root and rhizosphere function, and reducing infiltration of water. The effects of compaction on soils are often assessed by comparing bulk density and aeration porosity to critical or threshold values. Aeration porosity is often considered a more useful property than bulk density for assessing the effects of compaction on soils.

For example, a minor shift in total bulk density during puddling, or loss of soil structure, may be associated with a larger relative change in aeration porosity as macropores are shifted to smaller pores (Greacen and Sands 1980). As noted above, a post-harvesting study on silt loam and silt clay loam soils near Cranbrook (in southeastern BC), demonstrated that aeration porosity at 10 J/kg was more responsive to compaction-induced changes than relative change in total bulk density (Utzig and Thompson 1992). Also, Xu et al. (1992) demonstrated that gas diffusion is effectively zero at an aeration porosity of 10% for a range of soil textures. A commonly used standard is 15% aeration porosity (Boyer 1979).

Using the aeration porosity at 10 J/kg for comparison, the Repeated Machine Traffic and Light-Moderate compaction for both depths at Nakusp, the Repeated Machine Traffic at depth 6-8 cm for Golden, and the Light-Moderate compaction for both depths at Golden are close to or below the 15% threshold (Figure 3).

Thus, compacted surface soils on both sites have physical characteristics that may be limiting root growth. The effects on the site should be proportional to the area compacted, assuming all other factors remain constant. However, Greacen and Sands (1980) note that impact may not simply be related to area or degree of compacted soil because other interacting factors can enhance or offset a change in aeration porosity. The greater amount of aeration porosity lost at Nakusp may be offset by the lower soil disturbance on this site, compared to Golden.

The influence of compaction on tree growth depends on site and other factors. A destumping treatment carried out with Caterpillar D7 and D8 crawler-tractors near Golden yielded a post-treatment decrease in the growth of Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta*) on the impressions created by the inner tracks of the machines (Smith and Wass 1994). Decreased growth was also associated with calcareous microsites created through gouging, rutting, and stump excavation. Nutrient imbalances were suggested for these microsites. In contrast, the same researchers found a positive increase in tree growth after excavator destumping on a coarse, noncalcareous soil on Vancouver Island in Coastal BC (Wass and Smith 1997). At the Vancouver Island site, the main effect of destumping was to loosen the soil without significantly increasing the density.

Cultivation of the soil alone is often followed by a positive growth response (Greacen and Sands 1980; Froehlich and McNabb 1984). This raises an important question for future investigation: is the positive response in tree growth after destumping observed in some studies, a function of removing infected roots, or is the response due to a more favourable growth medium having been created by a simple cultivation effect in the absence of serious compaction? The latter is the objective of site preparation.

SUMMARY

Soil compaction significantly increased total bulk density at the Golden study site, decreased total plus two measures of aeration porosity at the Golden and Nakusp sites, and increased available water-storage capacity at both sites. The magnitude of the increase or decrease for these physical properties varied due to inherent site properties such as texture, slopes, and operational factors such as access construction, location, and seasonal conditions (soil moisture, frost, snow pack). Additional compacted spots with altered physical properties that may adversely affect tree growth are present on both sites but are not included in the current definition for countable disturbance. These microsites with Light-Moderate compaction occupied up to 16% of a treatment unit at the Golden site.

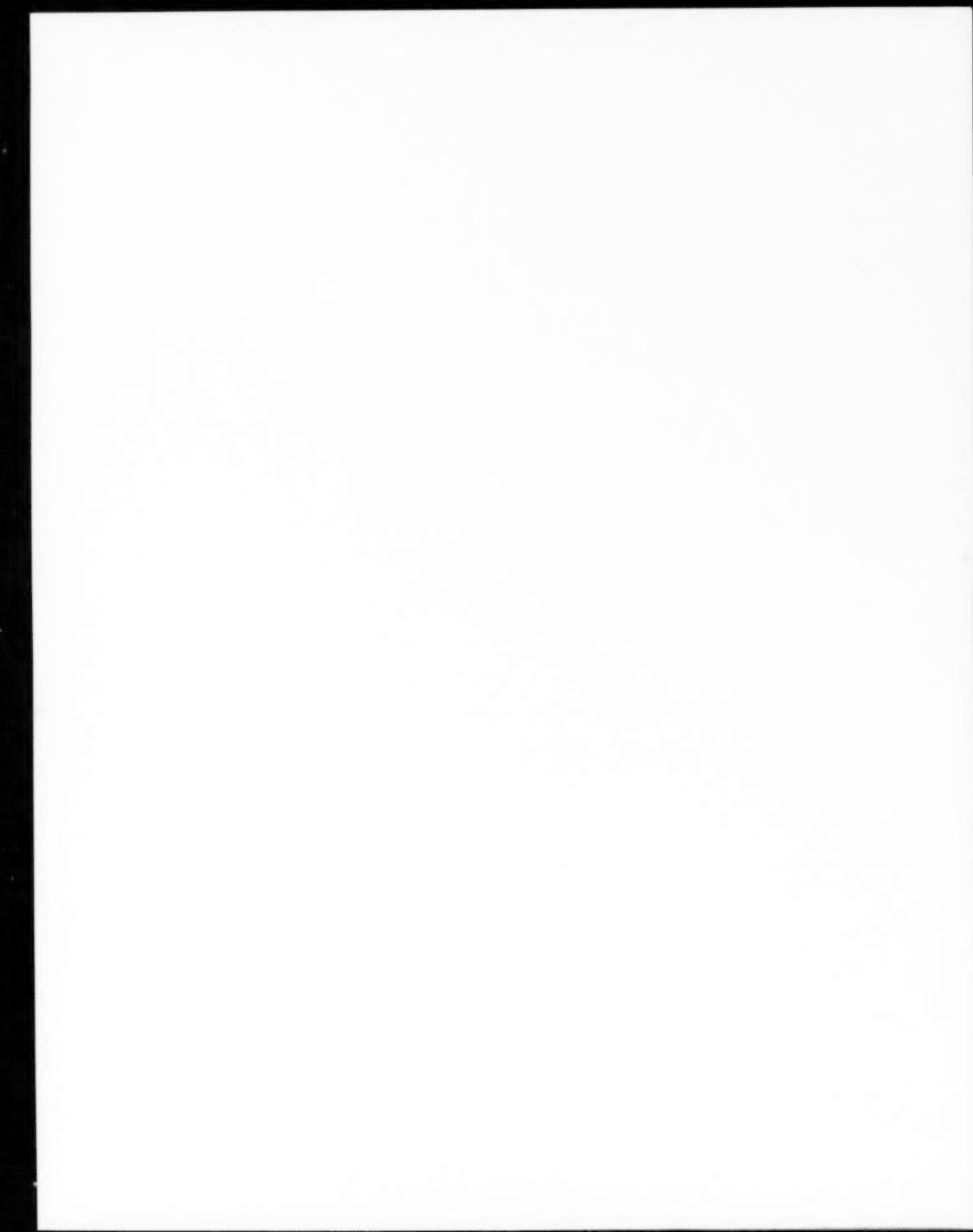
The effects of compaction on microsites were usually significant, irrespective of the harvesting method or basal area retention on a treatment unit. However, on both sites, aeration porosities for compacted samples were at or below critical values suggested by previous research. Pushover harvesting created greater levels of disturbance on both sites and the Golden site had greater levels of soil disturbance. The soil disturbance at the Golden site was also associated with increases in free carbonates (Quesnel and Curran 1999a and 1999b).

Thus, tree growth at the Golden site is expected to be reduced because compaction has reduced aeration porosity. Tree growth is also expected to be reduced because soil disturbance has exposed a greater level of free carbonates which can cause nutrient imbalances. Tree growth at the Nakusp site is expected to be negatively affected on the main skid trails because compaction has reduced aeration porosity of the soil to levels that restrict root growth. However, the overall effect at the Nakusp site is expected to be less than at the Golden site. Response of trees retained after partial harvesting, and growth of artificial and natural regeneration, are being monitored on the sites.

Finally, it was observed that, apart from the compaction, the effects of clearcut, pushover harvesting treatments on soils were similar to what happens when forested land is cleared and placed into cultivation by farmers. Many studies have documented the beneficial effects on tree growth of cultivating soils in situations where excessive compaction or exposure of unfavourable subsoils does not occur. However, the reader is cautioned that in extreme cases, similar site preparation can have a negative long-term effect on tree growth (Wass and Senyk 1999). The above suggests that cultivation alone could explain the tree growth response on pushover harvested sites. This could be equivalent to carrying out site preparation without undue soil compaction. A more localized cultivation, such as mounding or mixing, may provide similar benefits with fewer of the perceived costs of pushover harvesting, such as greater soil disturbance, soil compaction, or loss of woody debris.

Future studies should compare the tree-growth response on root disease infected sites after conventional ground-based harvesting, excavator destumping, and a microsite soil cultivation or mixing. A retrospective study may be possible if treatments, such as mounding, have been tried on sites with root disease.





RECOMMENDATIONS

Based on this soil disturbance and compaction research, a number of recommendations are appropriate in areas where root removal treatments are considered desirable for post-harvest tree growth. Quesnel and Curran (1999a) provide further details on the following recommendations.

1. Designated skid trails should be used, and post-harvest rehabilitation of skid trails should be undertaken.
2. Avoid refilling stump holes with woody debris.
3. Provide inexperienced machine operators with adequate training and supervision.
4. It is preferable to conduct pushover harvesting on frozen soils, deep snow packs (>1 m), or powder-dry soils.
5. Machine activity that creates compacted microsites smaller in surface area than permitted by the FPC criteria (Light-Moderate compaction) should be minimized, even where winter harvesting is used.

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